Processing various motion features and measuring RGCs pairwise correlations with a 2D retinal model

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Introduction

Most models of the early visual system consider simple and decorrelated retino-thalamic entries. However, studies have shown the retina is able to perform complex tasks using for instance motion anticipation to compensate delays in retino-cortical transmission [1], [2]. There exists models of retina anticipation, based on gain control at the level of retinal ganglion cells (RGCs) and bipolar cells, able to reproduce several motion features. These models consider 1D receptive field kernels, and thus does not take into account the anisotropy of RGCs receptive fields. Furthermore, they only simulate isolated RGCs whereas these cells are connected in the retina via amacrine cells. This raises the question of which part of the complex motion processing and anticipation is performed by the retina and which part is processed by the visual cortex. In this work, we propose a 2D retina model anticipation, implementing a realistic connectivity, allowing us to reproduce responses to different stimuli.The connectivity allows us to reproduce RGC's responses to stimuli occurring outside their receptive fields. We also present measures of correlations that emphasize the role of connectivity in motion response.

Anticipation model variability

The cascade model used in this work, from Chen & al. [2], is able to reproduce several motion processing features such as anticipation, alert response to motion onset and motion reversal. We first generalize the model in 2D and study anticipation variability, in an isotropic framework.

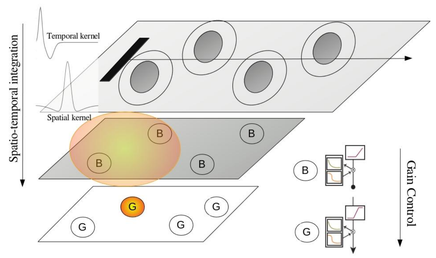

Figure 1: Schematic of the isotropic model.

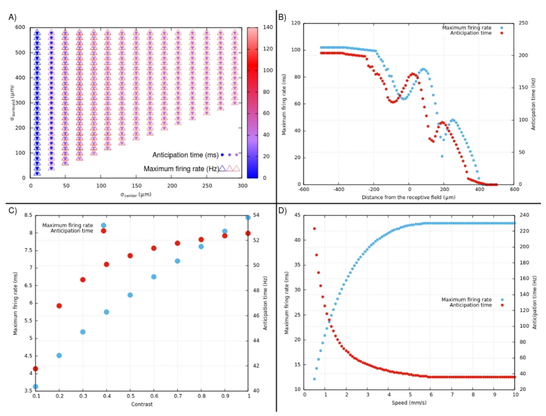

Figure 2: Variability of the model. A) Anticipation increases with the center std of the receptive field (RF), and is invariant with regards to the surround. B) Anticipation is maximum when the bar spans the whole RF and follows the RF shape. C) Anticipation increases with contrast and D) decreases with velocity.

Anisotropy implementation

Within the isotropic framework, when the receptive field is smaller than the bar's size, anticipation produces shape deformation.

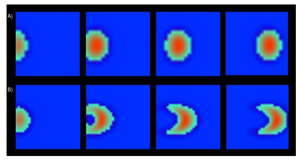

Figure 3: Schematic of the isotropic model.

Recent studies have shown that some retinal neurons are tuned to the orientation of elongated visual stimuli. In order to account for direction selectivity and study its effect on the object shape, we implement anisotropic filtering by rewriting the Gaussian of std σ_u and σ_v and rotation angle θ in a non orthogonal system of axes (x,ϕ). Integral separability and invariance along x axis allow the use of error function for half the computation.

$$\sigma_x = \frac{\sigma_u \sigma_v}{\sqrt{\sigma_v^2 \cos\theta^2 + \sigma_u^2 \sin\theta^2}}$$

$$\sigma_\phi = \frac{\sqrt{\sigma_v^2 \cos\theta^2 + \sigma_u^2 \sin\theta^2}}{\sin\phi}$$

$$\tan(\phi) = \frac{\sigma_v^2 \cos\theta^2 + \sigma_u^2 \sin\theta^2}{(\sigma_u^2 - \sigma_v^2)\cos\theta \sin\theta}$$

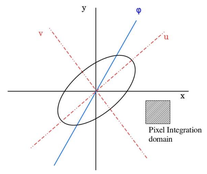

Figure 4: Filter transformation.

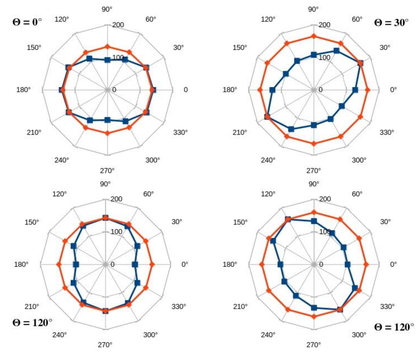

Figure 5: Tuning curves of anisotropic bipolar cells.

Can we avoid shape deformation by adding anisotropy ? We added anisotropic bipolar cells near the upper edge of the bar in order to reduce borders effects.

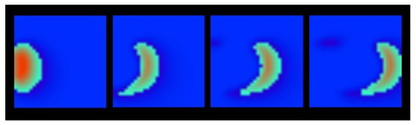

Figure 6: Anisotropy reduces shape deformation.

Connectivity model

In the retina, cells with different types are connected and interact in order to produce a visual output. The connectivity at the level of ganglion cells is due to interneurons called amacrines. Other cells, such us Parasol RGCs, are directly connected through gap junctions. We developed a connectivity model where a cell has X branches, each of which has length Y and angle Z. X and Y follow exponential distributions and Z a uniform distribution.

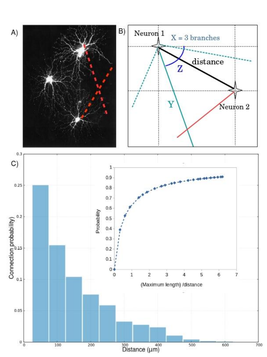

Figure 7: A) Morphology of Parasol ganglion cells. B) Geometry of the model C) Connection probability decreases with distance. Analytic distribution probability meets geometric simulation.

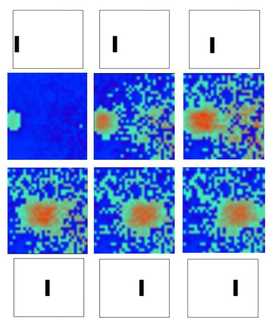

Figure 8: Long range connectivity between bipolar and ganglion cells increases anticipation. However, it puts the network in a highly excited state. Inhibitory connections, if involved in motion, have also to be taken into account.

Correlation of means and mean correlation

$$C_1(t) = \frac{E((\Pi_1 \cap \Pi_2)(t)) - E(\Pi_1(t))E(\Pi_2(t))}{\sqrt{E(\Pi_1(t))E(\Pi_2(t))}}$$

$$C_2(t) = E(\frac{(\Pi_1 \cap \Pi_2)(t) - \Pi_1(t)\Pi_2(t)}{\sqrt{\Pi_1(t)\Pi_2(t)}})$$

Correlations measurement

When the retina is presented with moving bar stimulus, transient and non stationary changes in the firing rates can occur. Thus, measuring correlations is not straight forward. Under the assumption that spike trains Π_1 and Π_1 are non-homogeneous Poisson processes, we compute correlation using a moving window algorithm. We then generated correlated Poisson processes to test our method.

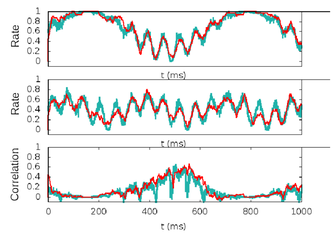

Figure 9: Computing the firing rates and correlation between two correlated Poisson processes with a moving window algorithm.

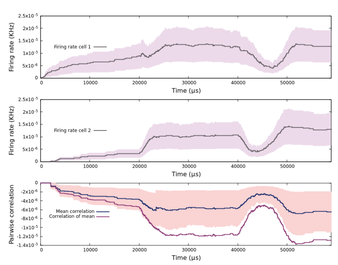

Figure 10: Pairwise correlation in experimental data (200 trials).

Correlations in the model

We want to compare correlation between two simulated cells with correlations in the data. For that we generate 200 sets of independent rasters. We find that the anti-correlation could be just an artifact related to the level of activity.

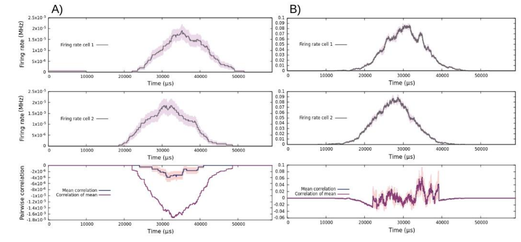

Figure 11: The effect of firing rate on correlation in simulated data (200 trials). A) Simulated data with a level of activity similar to recorded cells. B) Simulated data with higher firing rate.

Conclusion

We generalized Chen model, which reproduces anticipation and other motion features, in 2D, implementing anisotropy and a biologically inspired connectivity between bipolar and ganglion cells. We studied the effect of anticipation on the object shape in 2D and the effect of connectivity on anticipation. The study of correlations in recorded data doesn't provide any decisive conclusion, since the anti-correlation seem to be an artifact due to low levels of firing rate. Next step will be to implement inhibitory connections between RGCs through amacrine cells to reproduce differential motion. RGCs spike trains responding to motion stimuli can be then used as an input to a primary visual cortex model to study motion processing.

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Acknowledgements

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